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Emission factors of greenhouse gases from layer and broiler barns in Cameroon

N. Martin Ngwabie[a,*], Ada N. Acobta[b], Veronica E. Manga[b], Andrew C. VanderZaag[c]

[a] Department of Agricultural and Environmental Engineering, College of Technology, The University of Bamenda, Bambili, Cameroon
[b] Department of Environmental Science, Faculty of Science, University of Buea, Cameroon
[c] Science and Technology Branch, Agriculture and Agri-food Canada, Ottawa, Ontario, Canada

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ABSTRACT

Limited information is available in the literature on greenhouse gas (GHG) quantification from livestock production systems in Africa. Therefore, this project was carried out to generate baseline emission factors of methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) from broiler and layer barns with building design typical of Cameroon. Emissions were measured from two broiler barns during the entire production cycles and a layer barn for a limited period using flux chambers. Methane emission factors from the broiler barns with mud and cement floors were 0.96 ± 1.04 and 0.36 ± 0.17 mg $bird^{-1}$ hr^{-1} respectively, and 0.76 ± 0.56 mg $bird^{-1}$ hr^{-1} from the layer barn with cement floor. Nitrous oxide emission from the broiler barns with mud and cement floors were 12.94 ± 10.11 and 1.68 ± 1.02 mg $bird^{-1}$ hr^{-1} respectively, and 0.21 ± 0.28 mg $bird^{-1}$ hr^{-1} from the layer barn. Carbon dioxide emission factors from the broiler barns with mud and cement floors were 9327 ± 3508 and 25526 ± 6904 mg $bird^{-1}$ hr^{-1} respectively, and 8942 ± 36756 mg $bird^{-1}$ hr^{-1} from the layer barn. When scaled per livestock unit (LU), where 1 LU is 500 kg bird weight, CH_4 emissions were 0.16 ± 0.17 and 0.06 ± 0.03 g LU^{-1} hr^{-1} from the broiler barns, and 0.19 ± 0.14 g LU^{-1} hr^{-1} from the layer barn. Nitrous oxide emissions were 2.16 ± 1.69 and 0.28 ± 0.17 g LU^{-1} hr^{-1} from the broiler barns, and 0.05 ± 0.07 g LU^{-1} hr^{-1} from the layer barn. Broilers reared in management systems with wood shavings on mud floor had relatively high CH_4 and N_2O emissions compared to broilers on wood shavings and cement floor, with the contrary observed for CO_2. The emissions N_2O were significantly higher from broiler barns compared to layer barns. Emissions were higher in the mornings compared to later periods of the day. Given the observed results, GHG emission mitigation strategies need to be customised for each building design and management system.

1. Introduction

Increased concentrations of greenhouse gases (GHGs) such as methane (CH_4) and nitrous oxide (N_2O) are of environmental concern because of their implications on the global climate (Aneja et al., 2001; IPCC, 2001, 2013). Livestock production is an important source of GHG emissions into the atmosphere, with manure management and enteric fermentation accounting for 35–40% of the total anthropogenic CH_4 emissions and about 80% of CH_4 emitted from agriculture (FAO, 2006). Livestock activities also contribute 65% of the global anthropogenic N_2O emissions, and about 75–80% of the emissions from agriculture (FAO, 2006). As such, up to date data of emission factors from the main livestock production categories is needed for inventory purposes and to validate mitigation strategies.

There is a growing demand for livestock produce in African countries, which is leading to intensification of livestock production, especially poultry production systems (UNSIC, 2014). This expansion and intensification is likely to cause changes in the trend of GHG emissions. Despite these changes in livestock production, there is very limited information available in the literature on GHG emission rates from production systems in Africa and hardly any such data in Cameroon, where poultry houses are typically naturally ventilated with litter comprised of wood shavings. It has been projected that the developing world contributes 75% of global GHG emissions from ruminants and 56% of emissions from monogastrics (Herrero et al., 2013). Emissions of GHGs have mostly been quantified from poultry housing systems for climatic conditions that are typical of Europe and North America (Demmers et al., 1999; Guiziou and Beline, 2005; Fabbri et al., 2007). Africa emission factors of GHGs cannot be deduced directly from either Europe or North America studies due to differences in housing

* Corresponding author. Department of Agricultural and Environmental Engineering, College of Technology, The University of Bamenda, Box 39, Bambili, N. W. Region, Cameroon.
E-mail address: ngwabie@yahoo.co.uk (N.M. Ngwabie).

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design, management systems and climatic conditions.

Most emissions from poultry originate from manure management as opposed to ruminants where enteric emissions are equally important, with estimates suggesting that enteric fermentation accounts for about 80 and 30% of CH_4 in dairy cow and pig production respectively (Monteny et al., 2001). Methane production from manure proceeds through hydrolysis of hemicellulose and cellulose, acidogenesis, acetogenesis and finally methanogenesis (Monteny et al., 2006), with production rates determined by temperature and storage time (Alvarez et al., 2006; Chae et al., 2008). The use of wood shavings as bedding material increase the dry matter (DM) content and the carbon-to-nitrogen (C/N) ratio of the manure, which may reduce ammonia (NH_3) emissions, but rather increase N_2O or CH_4 emissions (Monteny et al., 2006). As such emission measurements from poultry should focus on the floor and manure.

Accurate country specific GHG reporting under the Paris Climate Agreement is essential for applying reliable GHG mitigation strategies. As such this project was carried out with the aim of deriving baseline data for CH_4 and N_2O, alongside carbon dioxide (CO_2) emission factors from broiler and layer houses with building design typical of Cameroon.

2. Materials and methods

2.1. Site description and technical performance

Measurements of GHG emission factors were carried out in two broiler barns and in a layer barn with housing designs and production systems typical of Cameroon.

2.1.1. Bwanda broiler barn

The Bwanda broiler barn is found in Bwanda, located in the Buea neighbourhood – the regional headquarters of the South West Region, Cameroon. The farm was made up of two buildings; one of which had an office space, a storage room and a brooding room. The second building was used as a broiler fattening barn. The broiler barn with dimension 65 × 15.5 m was divided into twenty rooms (~6.65 × 6.35 m each), a main entrance and a 1.7 m wide alleyway. The length of the barn was made of plywood up to a height of 0.6 m from the ground, and the remaining top part covered with wire mesh to enhance ventilation. The width of the barn was completely covered with plywood. The barn had a couple roof with two-sided ridge ventilation (Fig. 1). It had a mud floor covered with wood shavings as bedding material. The floor was completely cleaned and the barn disinfected between fattening cycles. The floor was completely covered with wood shavings at the start of the fattening period, and a fresh layer added after every 10 days. Manure removal was at the end of the fattening period. Due to some unexpected difficulties faced by farm management, the birds lasted 4 weeks in the brooding room rather than the usual 2 week period. They were moved into the fattening barn and distributed into four of the twenty rooms. The birds were progressively feed with the starter composed of 400 kg concentrate and 550 kg corn flour, the grower composed of 300 kg concentrate and 1000 kg corn flour, and the finisher composed of 200 kg concentrate and 1000 kg corn flour. Feed was supplied twice a day at 10 a.m. and 3:30 p.m. in rectangular wooden feeders. Water was consumed ad-libitum and was supplied using several automated and stationary drinkers. The birds were administered vaccine every 7 days through drinking water. A summary of the technical performance of the broilers was measured and presented in Table 1.

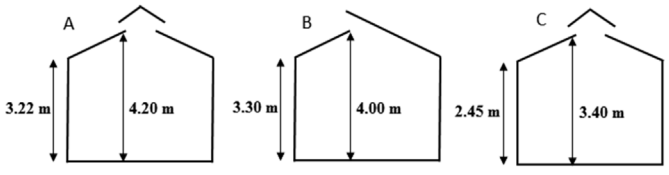

Fig. 1. Schematic of the Bwanda broiler barn (A), Bomaka broiler barn (B) and Nkwen layer barn (C).

2.1.2. Bomaka broiler barn

The Bomaka barn is found in Bomaka, also located in the Buea neighbourhood. Detailed production information is presented in Table 1. The farm had two buildings; one building had an office and a storage room while the other building was the broiler barn. The length of the barn was made of plywood to a height of 0.60 m from the ground with the remaining top part covered with a plastic mesh to ease ventilation. The width of the barn was completely covered with plywood. The barn had a couple roof with one-sided ridge ventilation (Fig. 1). The broiler barn with a dimension of 55 × 11.22 m, was divided into two equal rooms (27.50 × 11.22 m each). Both rooms were used for brooding and progressively extended for fattening the broilers. During the first two weeks, a small section of each room was enclosed with cardboard paper and heated with a charcoal heater for brooding. During the brooding period, the plastic mesh in the side walls were covered with polythene papers to conserve heat. After two weeks the cardboard paper and polythene linings were removed and the room used for fattening. The barn had a cement floor covered with wood shavings as bedding material. Manure management was similar to that in the Bwanda barn. Feed ration was similar to that in the Bwanda farm. The birds were fed manually at about 9 a.m. and 5 p.m. daily using rectangular wooden feeders. Water was supplied manually through stationary drinkers.

2.1.3. Nkwen layer farm

The Nkwen layer farm is found in Nkwen, located in the Bamenda neighbourhood – the regional headquarters of the North West Region. Detailed production information is presented in Table 1. The farm had two layer barns with dimension 40 × 12 m per barn. Each barn was partitioned into five rooms. On average, one of the barns had 3000 layers which were 19 months while the other barn had 5000 layers which were 6 months old (Table 1), evenly distributed in the rooms. Both long walls of the barn containing the older layers were constructed using mud blocks to a height of 0.8 m from the ground, while the upper section was made of bamboo to a height of 1.6 m. The long walls of the barn containing the younger birds was constructed using wood to a height of 0.8 m from the ground, while the upper section was made of wire mesh. The side walls of both barns were covered with mud blocks up to the ridge. The birds were fed twice a day with feed consumption data presented on Table 1. The feed was composed of corn, broken rice and concentrate. Eggs were collected twice a day (~9 a.m., 12 p.m. and 3 p.m.). The barn had a cement floor with wood shavings brought from the brooding room and applied just once before the birds were brought into the layer barns. No additional wood shavings was used throughout the laying cycle. Manure was removed intermittently through the laying cycle based on demand from buyers. Water consumption was through automatic drinkers. Natural ventilation was through the side walls and ridge (Fig. 1). Artificial lighting was put off between 9 p.m. and 5 a.m.

2.2. Gas concentration measurement

Emission rates were quantified using the non-steady state flux chamber method, where the change in gas concentrations over time in the headspace is related to the flux (Sommer et al., 2004; Duran and Kucharik, 2013). Gas samples were collected using two flux chambers. Chamber locations in the barns were varied during the measurement periods to account for the spatial heterogeneity of the litter surface. Collars were inserted into the litter a day prior gas sample collection. Gas samples were collected twice a week during the fattening periods in the Bwanda and Bomaka broiler barns. Headspace air in each chamber was sampled twice a day; in the mornings (10:40, 10:50, 11:00) and in

Table 1
Summary of management and performance data in the broiler and layer barns.

Parameters	Bwanda broiler barn	Bomaka broiler barn	Nkwen layer barn
Breed	Arbro	Arbro	Lohmann brown
Number of birds at the start of measurement	1528	2237	3000 and 5000
Number of birds at the start of measurement	1364	2177	3000 and 5000
Dead broiler (%)	11.52	2.77	NA
Stocking density (birds m^{-2})	8	4	8
Egg production (bird^{-1} 26 hr^{-1})	–	–	1
Total feed consumed (kg)	14750	18550	NA
Average feed intake during the measurement period (kg bird^{-1} day^{-1})	0.16	0.16	0.09–0.20
Average initial weight (kg $bird^{-1}$)	1.3	0.4	2
Average final weight (kg $bird^{-1}$)	3	3	2
Bird age at start of sampling (days)	35	21	210 and 570
Bird age at end of sampling (days)	59	53	214 and 573
Measurement season (wet season)	May	July	August
Bedding and floor	Wood shavings on mud floor	Wood shavings on concrete floor	Wood shavings on mud floor

NA: Data not available.

the evenings (15:40, 15:50, 16:00). Measurements lasted for 24 days in the Bwanda barn and for 32 days in the Bomaka barn. Seven rooms in the Nkwen layer barn were chosen for chamber placement; every other room in the barn with 3000 birds, and 4 rooms in the barn with 5000 layers. One chamber was always placed in at the centre of the rooms while the other chamber was rotationally placed to its North, East, South or West in the different rooms. Headspace air in each chamber was sampled thrice a day; in the mornings (09:00, 09:10, 09:20), afternoons (12:00, 12:10, 12:20) and evenings (16:00, 16:10, 16:20) for 7 days. Measurements in the layer barn lasted for a briefer period compared to the broiler barns because of the constant weight of the layers.

Changes in the enclosed air and manure temperatures were minimised by limiting the duration of chamber placement over the collars. Changes in emissions due to the heterogeneous nature of the manure surface was accounted for by changing the chamber locations, while temporal variations were accounted for by sampling two or three times per day and increasing the measurement duration to cover the growth cycle of the broilers.

A syringe was used to sample the headspace air in the chambers, and inject a 12 ml sample into an evacuated 10 ml glass vial. The gas sample vials were kept in a refrigerator before analyses for gas concentrations using a specially designed multi-greenhouse gas chromatograph (Varian 3800). The GC column was specified by the manufacturer and operated at 75 °C, while the system used an elector capture detector to detect N_2O, the detector temperature was 390 °C, and a flame ionization detector was used to detect CO_2 and CH_4 at a detector temperature of 250 °C. The carrier gas was He. The calibration range was 361.6 to 19,812 ppm for CO_2, 0.319–15.35 ppm for N_2O, and 1.03–200.1 ppm for CH_4.

2.3. Environmental and growth data measurements

Air temperature and relative humidity inside the barns were measured at a height of about 2 m from the ground using a Tinytag data logger (Gemini Data loggers, Chichester, UK) at 5 min intervals. During gas sampling periods in the Bwanda broiler and Nkwen layer barns, litter temperature was measured with a compost thermometer (TFA Dostmann, Wertheim, Germany). During days when gas samples were taken, birds were chosen at random and weighed.

2.4. Data analysis

Gas fluxes were calculated using the linear regression approach. A linear regression of the three points in each measurement gave a slope in units of ppmv min^{-1}. Regressed slopes were rejected if the coefficient of determination (R^2) was less than 0.80. The R^2 cut off value of 0.80 was chosen to ensure a reasonably good estimation of the rate of change in gas concentration. In another study that used the same methodology, the R^2 cut off value was 0.90 (Yu et al., 2013). The regressed slope was converted from ppmv min^{-1} to mg m^{-3} min^{-1} at the measured temperature and 760 mmHg. The slope was used to calculate the flux (mg m^{-2} min^{-1}) as presented in Equation (1).

$$\text{Flux} = \frac{slope \times headspace\ volume}{collar\ surface\ area} \quad (1)$$

where the headspace volume was 0.03 m^3 and the collar surface area was 0.108 m^2. Variations estimated to be less than 5% of the headspace volume were expected due to the uneven distribution of the manure on the floor.

3. Results and discussion

3.1. Environmental and growth data

Indoor air temperature was in the range of 21–34, 23–33, and 19–30 °C in the Bwanda, Bomaka and Nkwen barns respectively. Diurnal variations in the indoor air temperatures for the different barns is presented on an hourly basis in Fig. 2. Temperature variations that were less in the Bomaka broiler barn compared to the Bwanda broiler and Nkwen layer barns could be linked to the low stocking density (Table 1) and the one-sided ridge ventilation opening (Fig. 1). Litter temperature was in the range 30–35 and 16–25 °C in the Bwanda broiler and Nkwen layer barns respectively. The average gain in broiler weight was 0.07 and 0.08 kg day^{-1} in the Bwanda and Bomaka barns respectively.

3.2. Gaseous emission

Indoor gas concentrations in the barn was approximated by the headspace gas concentrations immediately the chamber was placed on the collar (Fig. 3). Mean indoor CH_4 concentration inside the layer barn (2.72 ppm) was slightly higher than values inside the broiler barns (2.31 ppm). However, indoor CH_4 concentrations in all the poultry barns were significantly lower than values from cattle (39.4 ± 16.9 ppm) and pig (~6.2–40 ppm) barns (Ngwabie et al., 2011a, 2011b). Unlike CH_4, N_2O concentration was higher inside the broiler barns (0.95 ± 0.49 ppm for Bwanda and 0.41 ± 0.03 ppm for Bomaka) compared to the layer barn (0.29 ± 0.04 ppm). Indoor N_2O concentrations were also higher inside the broiler barns when compared to measurements from cattle (0.26 ± 0.04 ppm) and pig (~0.38 ± 0.01 ppm) barns (Ngwabie et al., 2011a, 2011b).

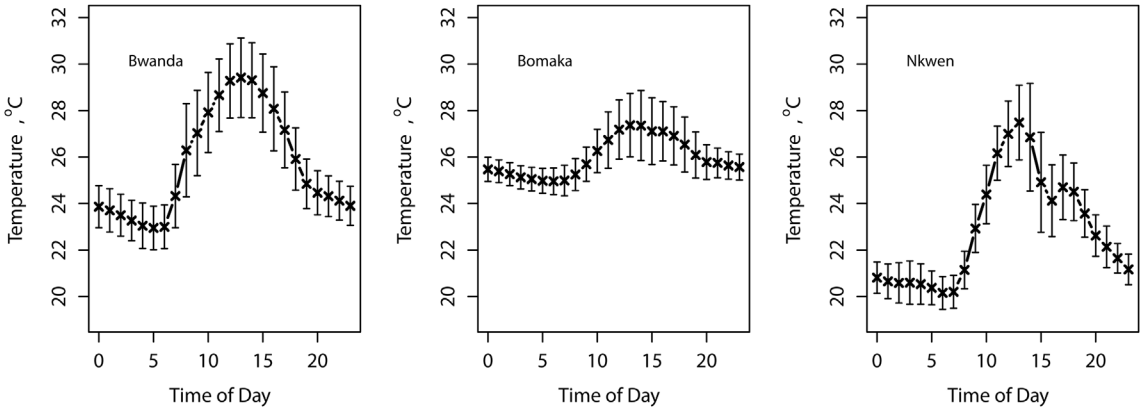

Fig. 2. Diurnal variations in indoor air temperatures in the broiler and layer barns during the measurement period. Data points present hourly averages for 312, 396 and 90 data points in the Bwanda, Bomaka, and Nkwen barns respectively, while arrow bars indicate standard deviations.

The emission rates of CH_4, N_2O and CO_2 expressed per litter surface area of the barns are presented in Table 2. Variations in the emission rates for the entire measurement periods are shown in Fig. 4 indicating larger variations for all the gases in the Bwanda broiler barn when compared to the other barns. There was no clear relationship between the emission rates from the manure and the duration of broiler fattening. The poor correlation could be associated to the management practise where wood shavings were periodically added to the manure and the barn surface area was gradually extended throughout the fattening period.

Given the occupied total surface area of about 169, 617 and 960 m^2 in the Bwanda, Bomaka and Nkwen barns respectively, and considering that the total number of birds at the end of the measurement period were approximately 1364, 2177 and 8000 in the Bwanda, Bomaka and Nkwen barns respectively, the emission rates in Table 2 can be scaled to the emission factors presented in Table 3. In the first part of Table 3, the emission factors are expressed per livestock unit (LU) while in the second part, they are expressed per the number of birds in the barns. The total LU in each barn is the ratio of the total mass of the birds at the end of the measurement period to 500 kg. Emission factors from selected literature are also presented in Table 3 for comparison with the present study. Methane emission factors for broiler in the present study were comparable to literature values. With regards to N_2O, the emission factor from the Bomaka barn was comparable to literature values while the emission factor from the Bwanda barn was exceptionally high compared to literature values. The higher N_2O emission factors from the broiler compared to the layer barn could be associated among other factors, to the different nutritional requirements (MacLeod et al., 2013). The extremely high N_2O emission from the Bwanda barn could be a result of the management practice with a high stocking density (~8 birds m^{-2}), and could also be related to the flooring and building design (Table 1). Variations within litter aggregates in animal faecal matter amended with bedding material such as wood shavings may create oxygen (O_2) level gradients within the aggregates and the depth of the manure (Firestone and Davidson, 1989; Groenestein et al., 1993; Monteny et al., 2001, 2006). As such, nitrification will occur near the surface of the aggregates and manure where O_2 is available, whereas denitrification will occur deeper within the aggregates and manure. In the absence of optimum conditions for nitrification and denitrification (change in temperature gradient, low C/N ratio among others),

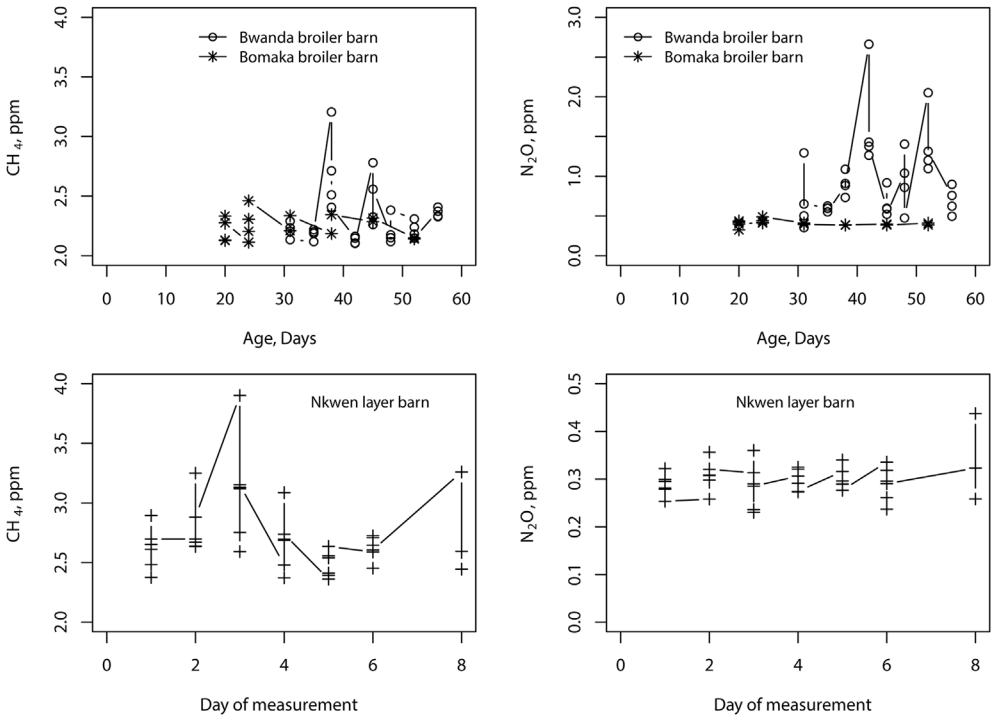

Fig. 3. Indoor air concentrations of CH_4 and N_2O, approximated as the headspace concentrations immediately the chamber was placed over the collar.

Table 2
Summary of gas emission rates from the broiler and layer barns (mg m^{-2} min^{-1}).

Gas	Bwanda broiler barn	Bomaka broiler barn	Nkwen layer barn
CH_4	0.129 ± 0.14 (0.005–0.473)	0.021 ± 0.01 (0.006–0.04)	0.105 ± 0.078 (0.004–0.327)
CO_2	1255 ± 472 (627–2068)	1501 ± 406 (749–2211)	1242 ± 5105 (530–2255)
N_2O	1.741 ± 1.36 (0.445–4.654)	0.099 ± 0.06 (0.015–0.235)	0.029 ± 0.039 (0.006–0.125)

Mean ± standard deviation (Range).

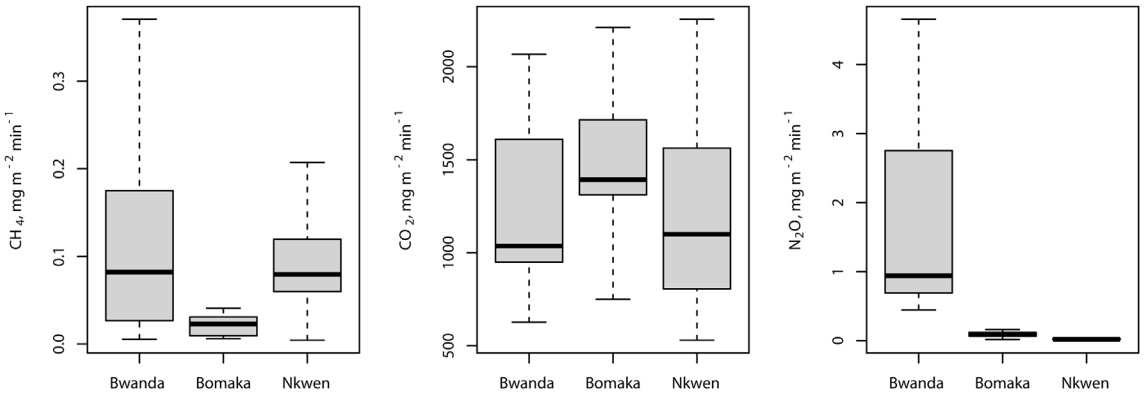

Fig. 4. Emission rates of CH_4, CO_2, and N_2O from two broiler barns (Bwanda and Bomaka) and a layer barn (Nkwen). The box represents the inter-quartile range with the median indicated at the centre. The whiskers extend to the most extreme emissions which is not more than 1.5 times the inter-quartile range from both ends of the box.

nitrification and denitrification do not go to completion, leading to the production of nitric oxide and N_2O from the poultry manure.

3.2.1. Diurnal variations in emission

Daily variations in emission rates revealed a rather decreasing pattern especially in the broiler barns, wherein the values in the morning were mostly higher than those measured in the later part of the day (Fig. 5). Analysis revealed a non-significant relationship between gas emissions and litter temperature. As such, the observed higher emission values in the mornings compared to later parts of the day could be associated to routine management (feeding and cleaning) and animal activities in the barns. The birds were expected to be more active in the mornings since they was no artificial lighting at night. Such behaviour is expected to lead to more droppings and manure disturbance.

4. Conclusions

This project was carried out to derive baseline data for CH_4 and N_2O alongside CO_2 emission factors from broiler and layer houses with building design typical of Cameroon. Broilers reared in management systems with wood shavings on mud floor have relatively high CH_4 and N_2O emissions compared to those reared with wood shavings on cement floor, with the contrary for CO_2 emissions. The emissions of N_2O are significantly higher from broiler barns compared to layer barns. Higher emissions were measured in the mornings compared to later periods of the day and were not related to the litter temperature, but could be related to routine management and animal activities. Given the variability in GHG emissions within each type of poultry production system, irrespective of the age or building design, mitigation strategies will have to be customised.

Table 3
Summary of gas emission factors from the broiler and layer barns and selected literature values.

	CH_4 (g LU^{-1} hr^{-1})	N_2O (g LU^{-1} hr^{-1})	CO_2 (g LU^{-1} hr^{-1})	Source
Bwanda broiler barn	0.16 ± 0.17	2.16 ± 1.69	1555 ± 585	This study
Bomaka broiler	0.06 ± 0.03	0.28 ± 0.17	4254 ± 1151	This study
Nkwen layer barn	0.19 ± 0.14	0.05 ± 0.07	2236 ± 9189	This study
Italy	0.11–2.64	Negligible	–	Fabbri et al., 2007
	CH_4 (mg $bird^{-1}$ hr^{-1})	**N_2O (mg $bird^{-1}$ hr^{-1})**	**CO_2 (mg $bird^{-1}$ hr^{-1})**	
Bwanda broiler	0.96 ± 1.04	12.94 ± 10.11	9327 ± 3508	This study
Bomaka broiler	0.36 ± 0.17	1.68 ± 1.02	25526 ± 6904	This study
Nkwen layer barn	0.76 ± 0.56	0.21 ± 0.28	8942 ± 36756	This study
South African	3.42 (layers), 2.28 (broilers)	–	–	Du Toit et al., 2013; DEA, 2014
IPCC - Poultry	13.66–18.21, Oceania	–	–	IPCC, 2006
Australia - Poultry	4.55	–	–	ANIR, 2012
USA - Poultry	11.38	NA	NA	EPA, 2016
Spain, broiler in summer	0.44	1.74	3840	Calvet et al., 2011
Spain, broiler in winter	1.87	2.13	4060	Calvet et al., 2011
Basque Country, caged layer barn	3.67	0.19	3490	Alberdi et al., 2016
Quebec-Canada. Caged layer barn, manure belt	3.03	0.29	3248	Fournel et al., 2012
Quebec-Canada. Caged layer barn, deep liquid manure pit	3.61	0.32	4110	Fournel et al., 2012
China-Poultry	1.71	0.57	–	Zhou et al., 2007

N_2 excretion from poultry is estimated in the literature in the range 0.60–1.10 kg $bird^{-1}$ $year^{-1}$ (IPCC, 2006; ANIR, 2012; Du Toit et al., 2013; DEA, 2014).

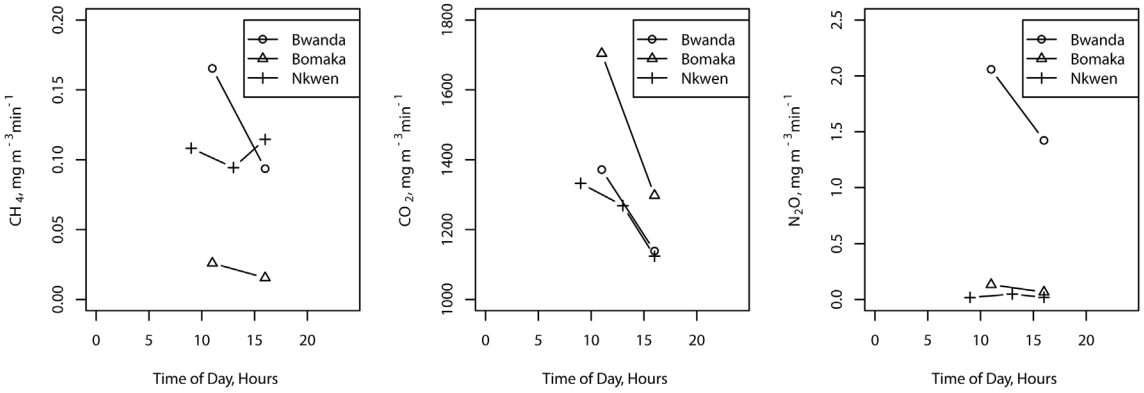

Fig. 5. Diurnal variations in the emission rates of CH_4, CO_2, and N_2O from two broiler barns (Bwanda and Bomaka) and a layer barn (Nkwen). Data points represent the mean of the mornings, afternoons or evenings sampling periods for the entire measurement duration.

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